Technical Sciences
Academy of Romania
www.jesi.astr.ro

Journal of Engineering Sciences and Innovation
Volume 5, Issue 3 / 2020, pp. 263-272

F. Petroleum and Mining Engineering

Received **11 May 2020** **Accepted 15 September 2020**
Received in revised from **28 August 2020**

Reverse method for determination of the qualitative wear occurring in the intermediate casing installed in oil and gas wells

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Abstract. The aim of the present paper is to set up a method for enhancing the casing design with emphases on the intermediate casing or liners, regarding the wear of the casing wall, which is appearing while drilling the subsequent horizontal production hole. By using this method, the well designer has the opportunity to prepare a "working envelope" in such a way that the further considerations as the well trajectory, dog leg severities, drilling parameters, type of mud, tool join geometry, should keep the casing wear in within technological limits imposed by the oil and gas operator, in order to maintain the intermediate casing (liner) integrity and do not diminish or affect at least the upcoming well stimulation programs, and well control measures. More than this, by using this method, the well trajectory can be optimized from the begging in such a way that the lateral forces on tool joints to be full as per recommendations of API RP7G [1], so increasing the safe work of the drilling string bellow the fatigue stress limits.

Keywords: intermediate casing, oil, gas, drilling, liner, well.

1. Introduction

The casing program is the core for any well design. In complex high-profile wells, as extended reach, long horizontal 2D and 3D even slant, S or J profile, having a big step out, if these wells are to be drilled in deep water, H_2S/CO_2, HPHT environment, then the integrity of the intermediate casing/liners covering the curved portions of the hole with high dog leg severities, is becoming a paramount.

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It is well known and demonstrated by practice that the intermediate casing or liners having the shoe set at the top of pay zone, should keep their integrity in full, for the body and at the connections level, in such a way that the well control measures should not be affected, the upcoming well stimulation programs should not be downgraded, and the tools, devices, equipment required inside of this casing should be installed and operated in proper conditions. In other words, the intermediate casing/liners should keep the burst and collapse pressure as rated in their technical specifications.

Unfortunately, drilling the subsequent sections will affect more or less the above conditions. Casing wear is a very known phenomenon which has direct and indirect causes.

As direct causes [2]:

• Wellbore Dog Leg Severity;
• Casing internal diameter and external diameter of drill string/ tool joint;
• The nature of casing and drill string surface;
• Lateral forces on tool joints, time exposure while rotating and penetrating inside casing;
• Casing wear coefficient.

As indirect factors:

• Annulus dimensions;
• Flow rate;
• Drilling fluid type;
• Temperature;
• pH value;
• Sand content.

Studies and experiments have shown that if the depth of wear in the casing wall is 10% of the wall thickness, then the burst pressure will drop at 90% of its original value and for a wall loss of 20% the collapse pressure is dropping to 80% of its original value [2]. Therefore, even the casing wear calculation is not standardized in industry, oil and gas operators are limiting the casing wear in between 4 - 6% as technologic limits [3].

In order to meet this requirement, the well designer should perform in advance casing wear simulation to see how the well trajectory (DLS – Dog Leg Severity), drilling parameters, type of drilling fluid, type of tool joints, time of exposure will affect the casing wear in such a way, that if the casing wear cannot be maintained under the technological limits, then some lengths should be reconsidered by changing the wall thickness.

2. The concept and method of calculation

The "Reverse" method is based on the hypothesis that during drilling with any bit diameter, having any intermediate casing diameter already set in place, using any type of special connections for the drilling string, the lateral forces shall be developed on the respective connections, covering a large spectrum of forces on tool joints, according to the API RP7 G diagram in figure 1 [1].

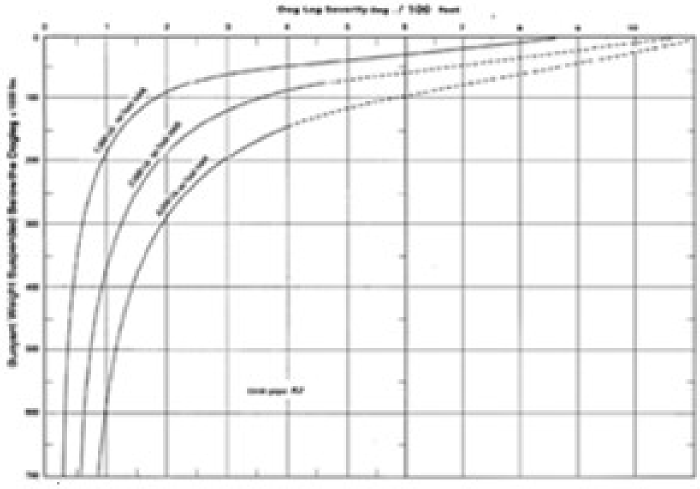

Fig. 1. Lateral Force on tool joint [1]

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In order to use this method, the following sequence of rationales should be applied:

a. Choose the sequence of intermediate casing that are intended to be run and will cover or is covering the area of buildup / drop down inclination and /or turning to the target azimuth.

b. Choose the sequence of drilling pipe with the connections proposed for use or which are used and rotated in the intermediate casing during drilling in the horizontal or subsequent deviated section.

c. All data are gathered as in the table 1.

Table 1. Sequence of casing, drill pipe and tool joints proposed for study

Intermediate casing									Drill pipe inside casing					Drill pipe Tool Joints						
D_e		D_i		t	Grade	Q_{unit}	$P_{collaps}$	P_{int}	D_e		Grade	Qnominal		Type	D_e		L_{TJ}		Torque optim	
in	mm	in	mm	mm		kg/m	Kpa	kpa	in	mm		lbs /ft	kg/m		in	mm	in	mm	lbs x ft	daN x m
13,375	339,7	12,415	315,3	12,2	L80	99,2	15600	34600	6,63	168,3	G105	27,7	41,2	HT65	8	203,2	26	660,4	59900	8122
13,375	339,7	12,347	313,6	13,1	L80	105,1	18400	37100				25,2	37,5	HT65	8	203,2	26	660,4	59900	8122
13,375	339,7	12,275	311,8	14	L80	112,4	21400	39700	5,5	139,7	G105	24,7	36,8	HT55	7	177,8	25	635	46300	6278
												21,9	32,6	HT55	7	177,8	25	635	46300	6278
									5	127	G105	25,6	38,1	HT50	6,625	168,3	24	609,6	42600	5777
												19,5	29,0	HT50	6,625	168,3	24	609,6	42600	5777
11,75	298,4	10,772	273,6	12,4	L80	87,6	21900	40200	6,63	168,3	G105	27,7	41,2	HT65	8	203,2	26	660,4	59900	8122
11,75	298,4	10,682	271,3	13,6	L80	94,9	26700	43900				25,2	37,5	HT65	8	203,2	26	660,4	59900	8122
11,75	298,4	10,586	268,9	14,8	L80	103,6	33600	47800	5,5	139,7	G105	24,7	36,8	HT55	7	177,8	25	635	46300	6278
												21,9	32,6	HT55	7	177,8	25	635	46300	6278
									5	127	G105	25,6	38,1	HT50	6,625	168,3	24	609,6	42600	5777
												19,5	29,0	HT50	6,625	168,3	24	609,6	42600	5777
10,75	273	9,85	250,2	11,4	L80	74,4	22200	40400	6,63	168,3	G105	27,7	41,2	HT65	8	203,2	26	660,4	59900	8122
10,75	273	9,76	247,9	12,6	L80	81	27700	44400				25,2	37,5	HT65	8	203,2	26	660,4	59900	8122
10,75	273	9,66	245,4	13,8	L80	88,6	35600	48900	5,5	139,7	G105	24,7	36,8	HT55	7	177,8	25	635	46300	6278
												21,9	32,6	HT55	7	177,8	25	635	46300	6278
									5	127	G105	25,6	38,1	HT50	6,625	168,3	24	609,6	42600	5777
												19,5	29,0	HT50	6,625	168,3	24	609,6	42600	5777
9,625	244,5	8,435	214,2	15,1	L80	85,2	54400	59700	5,5	139,7	G105	24,7	36,8	HT55	7	177,8	25	635	46300	6278
9,625	244,5	8,407	213,5	15,5	L80	86,7	56900	61100				21,9	32,6	HT55	7	177,8	25	635	46300	6278
9,625	244,5	8,365	212,7	15,9	L80	89,2	59700	62700	5	127	G105	25,6	38,1	HT50	6,625	168,28	24	609,6	42600	5777
												19,5	29,0	HT50	6,625	168,28	24	609,6	42600	5777
8,625	219,1	7,625	193,7	12,7	L80	62,4	47900	56000	5	127	G105	25,6	38,1	HT50	6,625	168,28	24	609,6	42600	5777
8,625	219,1	7,511	190,8	14,1	L80	71,5	59100	62300	4,5	114,3	G105	20	29,8	HT50	6,250	158,75	24	609,6	27600	3743
8,625	219,1	7,435	188,8	15,1	L80	75,9	66600	66600	4,5	114,3	G105	20	29,8	HT46	6,250	158,75	24	609,6	29100	3946
8,625	219,1	7,435	188,8	15,1	L80	75,9	66600	66600	4	101,6	G105	15,7	23,4	HT40	5,250	133,35	24	609,6	19200	2604
7,625	193,7	6,5	165,1	14,3	L80	62,5	74600	71100	4,5	114,3	G105	20	29,8	HT50	6,250	158,8	24	609,6	27600	3743
7,625	193,7	6,43	163,4	15,1	L80	66,1	79400	75300	4	101,6	G105	15,7	23,4	**HT40**	**5,250**	**133,4**	24	609,6	19200	2604
7,625	193,7	6,375	161,9	15,9	L80	68,7	83000	79100	3,5	88,9	G105	15,5	23,1	HT38	4,750	120,7	25,2	640,08	16200	2197
7	177,8	6,184	157,1	10,4	C90	42,3	54000	66800												
7	177,8	6,04	152,6	12,6	L80	51,1	70200	68700	4	101,6	G105	15,7	23,4	HT40	5,250	133,4	24	609,6	19200	2604
7	177,8	5,92	150,4	13,7	L80	55,5	78500	74500	3,5	88,9	G105	15,5	23,1	HT38	4,750	120,7	25,2	640,08	16200	2197
7	177,8	5,82	147,8	15	L80	59,8	85100	81400												

d. In this paper, it was considered for drilling pipe, tool joints with high torsion capability - Grant Prideco series HT (High Torque) series [4]. For reasons of normalization and uniformization, it shall be considered:

- 1000 m horizontal drilling right after intermediate casing;
- Motor drilling / 60 rpm at surface (RPM);
- 4,2 m / hour - penetration rate (ROP);
- Average wear factor (FF) 5,6-10 psi-1 corresponding for metal connections smooth [3].

e. As a mathematical model, the following theories, assumption and equations shall be used:

As per White and Dawson (1986), Archard (1953) casing wear caused on the inner surface of a casing string by the rotating tool joints of the drilling string is induced by the adhesive wear and depends mainly by the contact load between tool joint and casing surface, the hardness of the surface being worn away, the contact length between the two surfaces, and a wear coefficient [2].

In adhesive wear model [2], the energy required to remove a certain amount of material is compared with the total work done.

The wear efficiency is expressed as a report between the energy absorbed in wear and the total mechanical work done [2]:

$$K = \frac{V\,H}{\mu\,F_n\,S} \tag{1}$$

where:

K is wear efficiency;

F - friction coefficient / specific energy or wear factor;

V – volume of metal removed from the worn surface [in^3/ft];
H – Brinnell hardness;
μ – coeficient of friction between the wearing surfaces;
S – distance of sliding contact de contact traveled by the rotating tool joint;
F_n – normal contact forces between the surfaces.
K and H, respectively F values table 2 [2] are given for different casing steel garde or F values for different types of drilling fluids as in table 3 [3] - *ENI Casing Design Manual*.
Reputable oil and gas operators have performed experiments and laboratory tests in order to validate and modify the developed casing wear models to be applicable in real life and practical results.

Table 2. Wear properties of casing grades (White and Dawson, 1985) [2]

Wear properties of the casing grades				
Mud type	**Casing grade**	**Wear efficiency, K**	**K/H, [in^2/lbs]**	**Hardness, H [psi]**
Water based	K55	0,0001	$3,6^{-10}$	277778
	N80	0,00023	$8,1^{-10}$	283951
	P110	0,00063	$1,4^{-10}$	450000
Oil Based	K55	0,0006	$2,2^{-10}$	272727
	N80	0,0012	$3,9^{-10}$	307692
	P110	0,0017	$4,2^{-10}$	404762

Table 3. Experimentally determined wear factors [3]

Drilling fluid	**Tool joint**	**Wear factor (F), [E^{-10} psi^{-1}]**
Water + bentonite+ barite	Smooth	0,5 - 1
Water + bentonite + lubricant 2%	Smooth	0,5 - 5
Water + bentonite + drilled solids	Smooth	5 - 10
Water	Smooth	10 - 30
Water + bentonite	Neted	10 - 30
Water + bentonite + barite	Slightly rough	20 – 50
Water + bentonite + barite	Rough	50 - 150
Water + bentonite + barite	Very rough	200 - 400

Regardless what is the source of selection tor the wear factor, this is meassured in E^{-10} psi^{-1} so for example, a wear factor of "8" means 8 E^{-10} psi^{-1} which shall be used effectively in calculations. In the models used to predict the qualitative wear it is very important to pick up a realistic wera factor F.
The formula (1) should be re-writen in a more convenient form for further calculations, therefore the following abreviations and considerations shall be used in such a way that it can be obtained the term V which is the volume of material removed from the inner face of the subject casing, due of the adhesive wear.
V_z - Rate of penetration [ft/hr];
L_h – Length of the subsequent borehole to be drilled – usually the length of the production hole having alreadi set the intermediate casing which is the exercise subject casing [ft];
r_{TJ} - Tool joint radius [in];
D_{TJ} - External diameter of the tool joint [in];

L_{TJ} - Length of the tool joint [ft];
ω - Rotation per minute / rotational speed of the drilling string;
DP_{JL} - Length between two consecutive tool joints (drill pipe body length) [ft];
T – Expossure time [3]:

$$T = \frac{L_h\, L_{TJ}}{DP_{JL}} \quad \text{[hrs]}; \tag{2}$$

R – Well curvature radius for each point where the calculations are done in order to determine the axial forces [ft];
S – Sliding distance of the tool joint while rotating / unit of drilled hole [ft];
F_a – Axial force in drilling string in each calculation point (every 100 ft or every 30 m);
F_n - Normal force on tool joint:

$$F_n = L_{TJ}\,\frac{F_a}{R} \quad \text{[lbs/ft]}; \tag{3}$$

L = Lateral load on drill pipe:

$$L = F_n\, L_{TJ}\, DP_{JL} \quad \text{[lbs/ft]}. \tag{4}$$

As has been mentionned above, the wear factor which controlls the wear efficiency, is determined effectively in laborators for different conditions [2, 3].
The equation (1) can be re formulated as:

$$V = \frac{60\pi\, F\, L\, D_{TJ}\, \omega\, L_h}{V_z} \tag{5}$$

where:
V is the volume of casing wear / unit length [in^3/ ft];
F - wear factor factorul de E^{-10} psi^{-1};
L - lateral load on drill pipe / unit length [lbs/ft];
D_{TJ} – external diameter of tool joint [in];
L_h - drilled length [ft];
V_z – rate opf penetration [ft /hr];
ω – rotations per minute.
The length of tool joint and the length of drill pipe tube does not appear in the above equation because they are not affecting under linear model considerations the metal quantity lost by wear.
Equation (5) is applied for the lateral forces are picked up from the diagrame of figure 1, respectively from 25 lbs to 3500 lbs (11 daN to 1540 daN), and the drilling parameters as per Section **d**.
Also, in this paper calculations are done just for the 7 in casing covering 3-unit weights and two type of tool joints. The results are representing the qualitative wear results, and are displayed in table 4. The graphic representation, is reflected in figure 2, including the technological limits for the collapse pressure and the allowable normal forces on tool joint imposed by well design (trajectory shape, subsurface equipment limitations, maximum dog legs, friction factors etc.)

Table 4. Qualitative wear, in %, for a speciffic casing and tool joint

Casing 7 " L80								Tool Joint type																							
Parameters								HT40 on drill pipe 4 " G105 new												HT38 on drill pipe 3 1/2" G105 new											
Forta Lateral Force on Tool Joint		Subsequent length drilling section		RPM	Rate of Penetration		Wear Factor F	OD Tool Joint		L Tool Joint		Lateral load on drill pipe / unit length		Wear volume		% wear wall for casing 7 " L80 (C90) and Q unit kg/m				OD Tool Joint		L Tool Joint		Lateral load on drill pipe / unit length		Wear volume		% wear wall for casing 7 " L80 (C90) and Q unit kg/m			
																42,3	51,1	55,5	59,8									42,3	51,1	55,5	59,8
Lbs	daN	ft	m	rpm	ft	m	e-10psi-1	in	mm	in	mm	Lbs/ft	daN/m	in3/ft	g/m	(C90)%	%	%	%	in	mm	in	mm	Lbs/ft	daN/m	in3/ft	g/m	(C90)%	%	%	%
25	11	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	21,4	31,899	0,1511	63,359	0,15%	0,12%	0,11%	0,11%	4,75	120,65	25,2	640,08	22,5	33,5	0,16	66,53	0,16%	0,13%	0,12%	0,11%
40,3	17,7	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	34,5	51,421	0,2436	102,14	0,24%	0,20%	0,18%	0,17%	4,75	120,65	25,2	640,08	36	54,0	0,26	107,2	0,25%	0,21%	0,19%	0,18%
75	33	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	64,3	95,696	0,4534	190,08	0,45%	0,37%	0,34%	0,32%	4,75	120,65	25,2	640,08	68	100,5	0,48	199,6	0,47%	0,39%	0,36%	0,33%
100	44	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	85,7	127,6	0,6045	253,44	0,60%	0,50%	0,46%	0,42%	4,75	120,65	25,2	640,08	90	134,0	0,63	266,1	0,63%	0,52%	0,48%	0,44%
125	55	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	107	159,49	0,7556	316,8	0,75%	0,62%	0,57%	0,53%	4,75	120,65	25,2	640,08	113	167,5	0,79	332,6	0,79%	0,65%	0,60%	0,56%
150	66	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	129	191,39	0,9068	380,16	0,90%	0,74%	0,68%	0,64%	4,75	120,65	25,2	640,08	135	201,0	0,95	399,2	0,94%	0,78%	0,72%	0,67%
175	77	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	150	223,29	1,0579	443,52	1,05%	0,87%	0,80%	0,74%	4,75	120,65	25,2	640,08	158	234,5	1,11	465,7	1,10%	0,91%	0,84%	0,78%
200	88	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	171	255,19	1,209	506,87	1,20%	0,99%	0,91%	0,85%	4,75	120,65	25,2	640,08	180	267,9	1,27	532,2	1,26%	1,04%	0,96%	0,89%
225	99	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	193	287,09	1,3601	570,23	1,35%	1,12%	1,03%	0,95%	4,75	120,65	25,2	640,08	203	301,4	1,43	598,7	1,42%	1,17%	1,08%	1,00%
250	110	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	214	318,99	1,5113	633,59	1,50%	1,24%	1,14%	1,06%	4,75	120,75	25,2	640,08	225	334,9	1,59	665,3	1,57%	1,30%	1,20%	1,11%
275	121	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	236	350,89	1,6624	696,95	1,65%	1,36%	1,26%	1,17%	4,75	120,75	25,2	640,08	248	368,4	1,75	731,8	1,73%	1,43%	1,32%	1,22%
300	132	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	257	382,79	1,8135	760,31	1,80%	1,49%	1,37%	1,27%	4,75	120,75	25,2	640,08	270	401,9	1,9	798,3	1,89%	1,56%	1,44%	1,33%
325	143	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	279	414,68	1,9646	823,67	1,95%	1,61%	1,48%	1,38%	4,75	120,75	25,2	640,08	293	435,4	2,06	864,9	2,04%	1,69%	1,56%	1,45%
350	154	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	300	446,58	2,1158	887,03	2,10%	1,74%	1,60%	1,48%	4,75	120,75	25,2	640,08	315	468,9	2,22	931,4	2,20%	1,82%	1,68%	1,56%
375	165	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	321	478,48	2,2669	950,39	2,25%	1,86%	1,71%	1,59%	4,75	120,75	25,2	640,08	338	502,4	2,38	997,9	2,36%	1,95%	1,80%	1,67%
425	187	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	364	542,28	2,5691	1077,1	2,55%	2,11%	1,94%	1,80%	4,75	120,75	25,2	640,08	383	569,4	2,7	1131	2,67%	2,21%	2,04%	1,89%
450	198	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	386	574,18	2,7203	1140,5	2,70%	2,23%	2,05%	1,91%	4,75	120,75	25,2	640,08	405	602,9	2,86	1197	2,83%	2,34%	2,16%	2,00%
475	209	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	407	606,08	2,8714	1203,8	2,85%	2,36%	2,17%	2,01%	4,75	120,75	25,2	640,08	428	636,4	3,01	1264	2,99%	2,47%	2,28%	2,11%
500	220	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	429	637,98	3,0225	1267,2	3,00%	2,48%	2,28%	2,12%	4,75	120,75	25,2	640,08	450	669,9	3,17	1331	3,15%	2,60%	2,40%	2,22%
550	242	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	471	701,77	3,3248	1393,9	3,30%	2,73%	2,51%	2,33%	4,75	120,75	25,2	640,08	495	736,9	3,49	1464	3,46%	2,86%	2,64%	2,45%
600	264	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	514	765,57	3,627	1520,6	3,59%	2,98%	2,74%	2,54%	4,75	120,75	25,2	640,08	540	803,8	3,81	1597	3,77%	3,12%	2,88%	2,67%
650	286	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	557	829,37	3,9293	1647,3	3,89%	3,22%	2,97%	2,75%	4,75	120,75	25,2	640,08	585	870,8	4,13	1730	4,09%	3,38%	3,12%	2,89%
700	308	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	600	893,17	4,2315	1774,1	4,19%	3,47%	3,20%	2,97%	4,75	120,75	25,2	640,08	630	937,8	4,44	1863	4,40%	3,65%	3,36%	3,11%
750	330	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	643	956,96	4,5338	1900,8	4,49%	3,72%	3,42%	3,18%	4,75	120,75	25,2	640,08	675	1004,8	4,76	1996	4,72%	3,91%	3,60%	3,34%
800	352	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	686	1020,8	4,836	2027,5	4,79%	3,97%	3,65%	3,39%	4,75	120,75	25,2	640,08	720	1071,8	5,08	2129	5,03%	4,17%	3,84%	3,56%
850	374	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	729	1084,6	5,1383	2154,2	5,09%	4,22%	3,88%	3,60%	4,75	120,75	25,2	640,08	765	1138,8	5,4	2262	5,35%	4,43%	4,08%	3,78%
900	396	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	771	1148,4	5,4405	2280,9	5,39%	4,46%	4,11%	3,81%	4,75	120,75	25,2	640,08	810	1205,8	5,71	2395	5,66%	4,69%	4,32%	4,00%
950	418	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	814	1212,2	5,7428	2407,7	5,69%	4,71%	4,34%	4,03%	4,75	120,75	25,2	640,08	855	1272,8	6,03	2528	5,98%	4,95%	4,56%	4,23%
1000	440	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	857	1276	6,045	2534,4	5,99%	4,96%	4,57%	4,24%	4,75	120,75	25,2	640,08	900	1339,7	6,35	2661	6,29%	5,21%	4,79%	4,45%
1050	462	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	900	1339,7	6,3473	2661,1	6,29%	5,21%	4,79%	4,45%	4,75	120,75	25,2	640,08	945	1406,7	6,66	2794	6,61%	5,47%	5,03%	4,67%
1100	484	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	943	1403,5	6,6495	2787,8	6,59%	5,46%	5,02%	4,66%	4,75	120,75	25,2	640,08	990	1473,7	6,98	2927	6,92%	5,73%	5,27%	4,89%
1150	506	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	986	1467,3	6,9518	2914,5	6,89%	5,70%	5,25%	4,87%	4,75	120,75	25,2	640,08	1035	1540,7	7,3	3060	7,23%	5,99%	5,51%	5,12%
1200	528	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1029	1531,1	7,254	3041,2	7,19%	5,95%	5,48%	5,09%	4,75	120,75	25,2	640,08	1080	1607,7	7,62	3193	7,55%	6,25%	5,75%	5,34%
1250	550	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1071	1594,9	7,5563	3168	7,49%	6,20%	5,71%	5,30%	4,75	120,75	25,2	640,08	1125	1674,7	7,93	3326	7,86%	6,51%	5,99%	5,56%
1300	572	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1114	1658,7	7,8585	3294,7	7,79%	6,45%	5,94%	5,51%	4,75	120,75	25,2	640,08	1170	1741,7	8,25	3459	8,18%	6,77%	6,23%	5,78%
1350	594	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1157	1722,5	8,1608	3421,4	8,09%	6,70%	6,16%	5,72%	4,75	120,75	25,2	640,08	1215	1808,7	8,57	3592	8,49%	7,03%	6,47%	6,01%
1400	616	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1200	1786,3	8,463	3548,1	8,39%	6,94%	6,39%	5,93%	4,75	120,75	25,2	640,08	1260	1875,6	8,89	3726	8,81%	7,29%	6,71%	6,23%
1450	638	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1243	1850,1	8,7653	3674,8	8,69%	7,19%	6,62%	6,15%	4,75	120,75	25,2	640,08	1305	1942,6	9,2	3859	9,12%	7,55%	6,95%	6,45%
1500	660	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1286	1913,9	9,0675	3801,6	8,99%	7,44%	6,85%	6,36%	4,75	120,75	25,2	640,08	1350	2009,6	9,52	3992	9,44%	7,81%	7,19%	6,67%
1550	682	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1329	1977,7	9,3698	3928,3	9,29%	7,69%	7,08%	6,57%	4,75	120,75	25,2	640,08	1395	2076,6	9,84	4125	9,75%	8,07%	7,43%	6,90%
1600	704	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1371	2041,5	9,672	4055	9,59%	7,94%	7,31%	6,78%	4,75	120,75	25,2	640,08	1440	2143,6	10,2	4258	10,07%	8,33%	7,67%	7,12%
1650	726	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1414	2105,3	9,9743	4181,7	9,89%	8,18%	7,53%	6,99%	4,75	120,75	25,2	640,08	1485	2210,6	10,5	4391	10,38%	8,59%	7,91%	7,34%
1700	748	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1457	2169,1	10,277	4308,4	10,19%	8,43%	7,76%	7,20%	4,75	120,75	25,2	640,08	1530	2277,6	10,8	4524	10,69%	8,85%	8,15%	7,56%
2000	880	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	1714	2551,9	12,09	5068,7	11,98%	9,92%	9,13%	8,48%	4,75	120,75	25,2	640,08	1800	2679,5	12,7	5322	12,58%	10,42%	9,59%	8,90%
3000	1320	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	2571	3827,9	18,135	7603,1	17,97%	14,88%	13,70%	12,71%	4,75	120,75	25,2	640,08	2700	4019,2	19	7983	18,87%	15,62%	14,38%	13,35%
3500	1540	3282	1000	60	14	4,267	5,6E-10	5,25	133,35	24	609,6	3000	4465,8	21,158	8870,3	20,97%	17,36%	15,98%	14,83%	4,75	120,75	25,2	640,08	3150	4689,1	22,2	9314	22,02%	18,23%	16,78%	15,57%

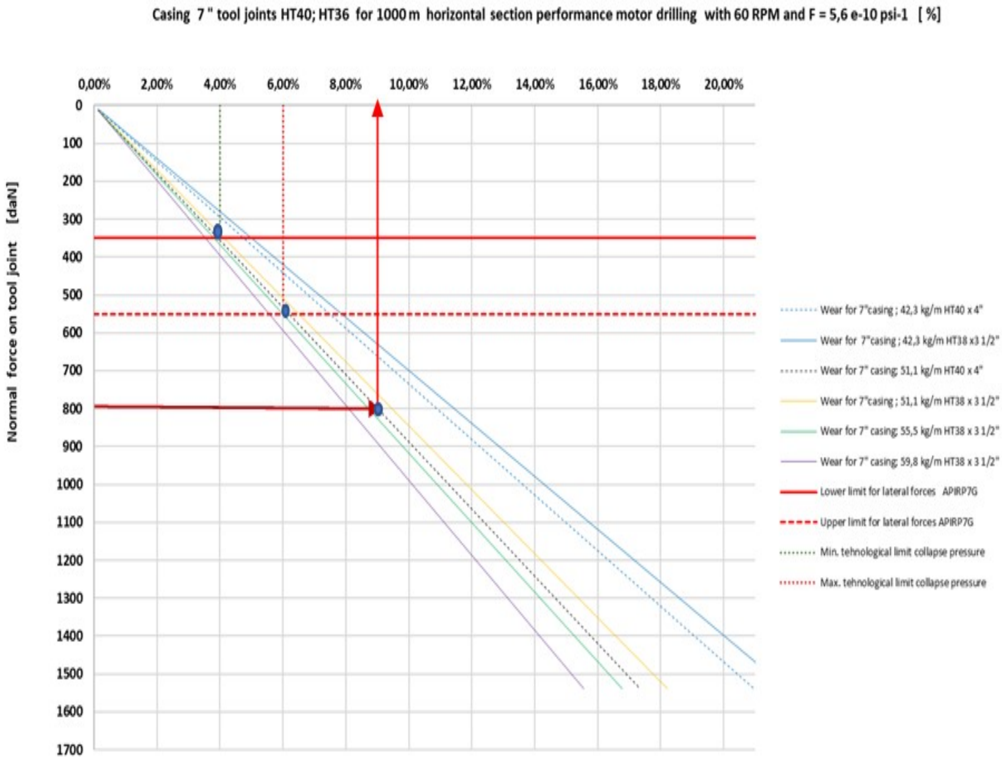

Fig. 2. Qualitative wear, in %, for a speciffic casing OD and tool joint vs. lateral forces on tool joint.

3. Graphic interpretation

- The well designer is imposing a range of normal forces on tool joint deriving from the limits of miscellanea equipment which shall be operated / installed in the hole while drilling the production hole or while running completion; in this case 350 to 550 daN on tool joint. At this point the Dog Leg Severity, the shape of the well does not matter.
- The well designer is imposing the technological limits for the intermediate casing qualitative wear, as per the Company policies, in this case 4 to 6%.
- From the casing design (biaxial or triaxial) has resulted as acceptable, an intermediate casing of 7 in OD; L80; 51,1 kg/m.
- The drilling contractor will provide a drilling string consiting of drill pipe OD 4 in; G105 with HT40 tool joints, working inside of the intermediate casing.
- The subsequent horizontal section will have 1000 length, and shall be drilled with positive displacemet motor having 60 RPM applied from surface top drive system.
- The assumed ROP will be 4,2 m/hr.
- From the imposed lateral forces on tool joint and drilling with the above conditions, the estimate of qualitative wear is going to be 4 to 6 % being as per the Company policies. Consequently, the well planner - directional drilling service company can set a well trajectory which may induce as per the torque and drag

models, lateral forces on tool joint no more than 550 daN, providing there are not other technical limitations.Therefore, this casing is accepted from the qualitative wear stand point.
- If the well planner, after running torque and drag models related to the trajectories & operations, comes up with lateral forces on tool joint over 550 daN (say 800 daN for example), and he can not optimize the dog leg severities, trajectory shape etc., for realistic technical reasons, then because the qualitative wear will jump to 9%, sure the subject intermediate casing profile should be changed, and also the drilling string/tool joints reconsidered.

4. Conclusions and recommendations

Based on the results and analysis, the following conclusions are extracted:
• Among other factors, casing wear is dependent of the well trajectory path, with emphasis on the Dog Leg Severity values, drilling parameters including the ROP.
• Although this method is referring only to the qualitative aspect of the casing wear, neglecting totally the wear geometry and the depth of the wear grove, still remains a fast tool in order to asses the percentage of the casing wear.
• This method is sensitive with the selection of the wear factor.
• Beside of the percentage of casing wear per unit length, the casing wear is developing under a very specific pattern and geometrical form, and dimensions. This subject is not treated in this paper, but this is another very important matter to be considered.
• The casing wear values and positions, even from qualitative stand point only, is to be carefully considerate in well design – casing design and drilling operations for directional, ERD, horizontal wells, HPHT, critical sour wells with emphasis on well control scenarios, well stimulation scenarios, and all operations which are related with the casing burst and collapse pressures.
• The calculation of lateral forces on tool joints should be included in any scope of work for any well planner-directional drilling service company.
• Using this method, it will keep safe not only the intermediate casing from the qualitative wear stand point, but also the drilling string because using the API RP7G lateral forces on tool joint diagram, will imply in fact rotating these pipes in curved holes having maximum dog leg severity below the values generating high fatigue stress.
In order to reduce the casing wear, oil and gas operators, well designers, field representatives, are encouraged to use some preventive measures as:
- design the well at minimum DLS and take into considerations real DLS 1.75 – 2 times higher than designed;
- reduce RPM at the rotary table / top drive system so use motor performance drilling;
- minimize the exposure time by increasing the ROP;
- employ the drill pipe protectors;
- use tool joint materials to minimize the casing wear;

-use thicker wall casing along such intervals where the casing wear is to occur at high values;
- keep the drilling fluid clean and add lubricant to minimize the casing wear;
- perform time to time casing wear prediction calculations, and if the well is high profile, run specific caliper logging suites to determine the real casing wear and compare against the predicted.

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